



TEAWS 2007 Orion Passive Thermal Control Overview

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Topics



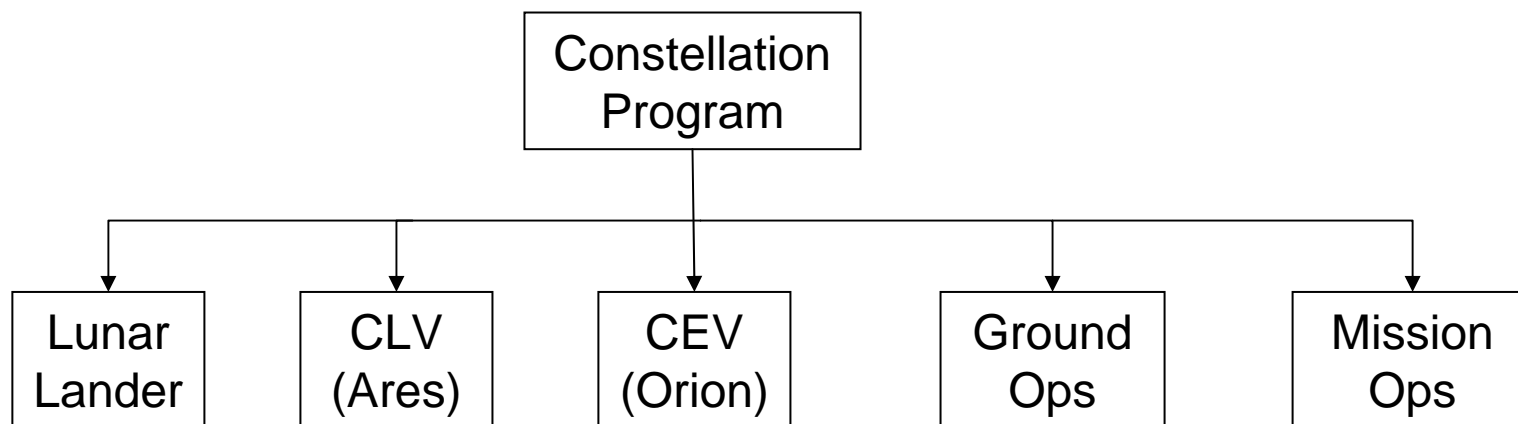
- Orion in CxP Hierarchy
- General Orion Description/Orientation
 - Module Descriptions and Images
- Orion PTCS Overview
 - Requirements/Interfaces
 - Design Reference Missions
 - Natural Environments
 - Thermal Models
 - Challenges/Issues
 - Testing



Orion in CxP Hierarchy



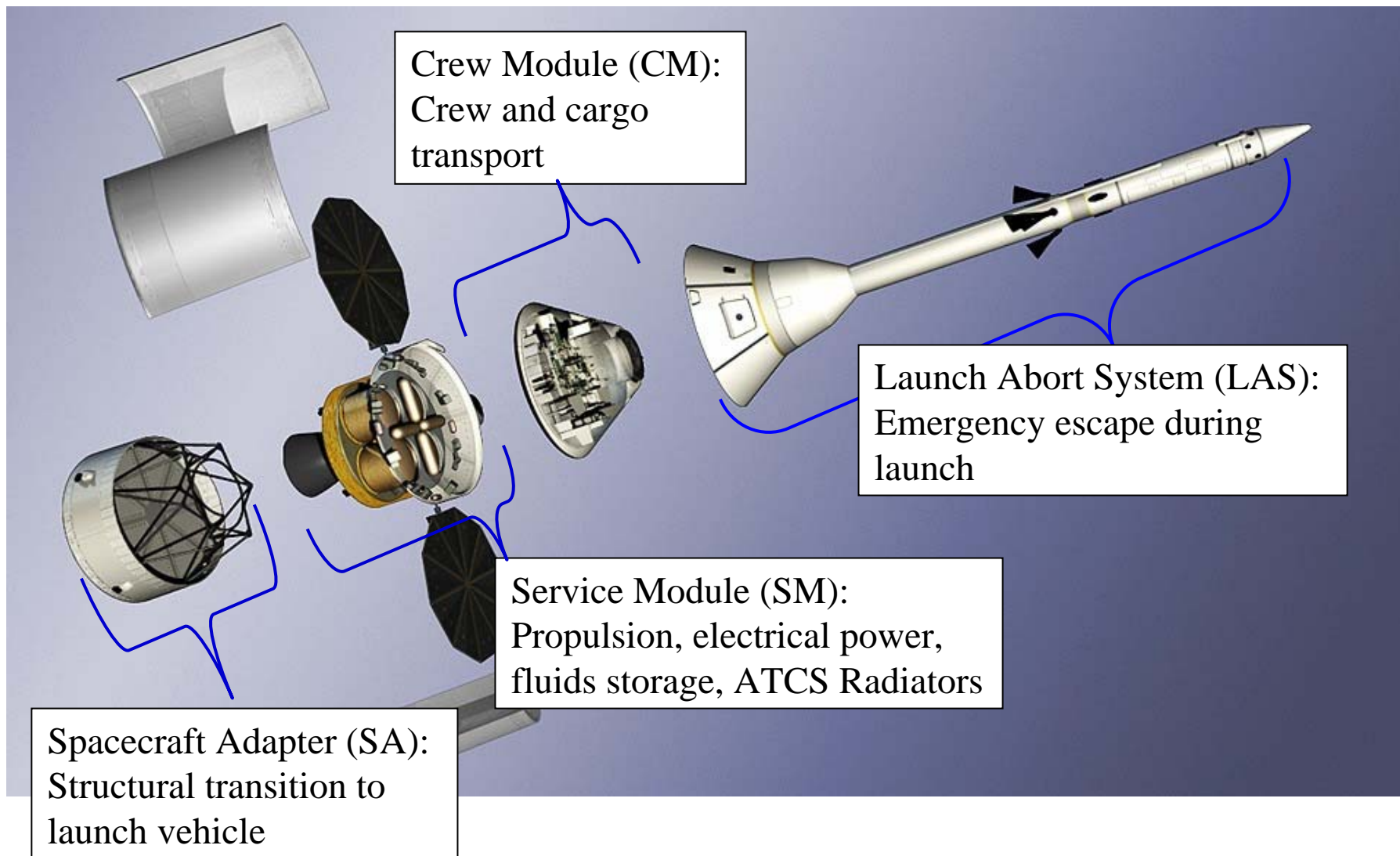
- Orion is the main crewed vehicle in the Constellation program.
 - Designed to carry 6 crew to/from ISS or 4 crew to/from the Moon.
- Billed as the Shuttle “replacement”
- First Flight in 2014
 - First unit produced in 2012
- Will be launched on top of an Ares I vehicle.





General Orion

Description/Orientation

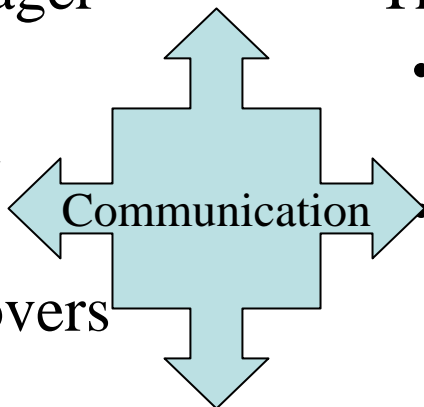




Orion PTCS Team



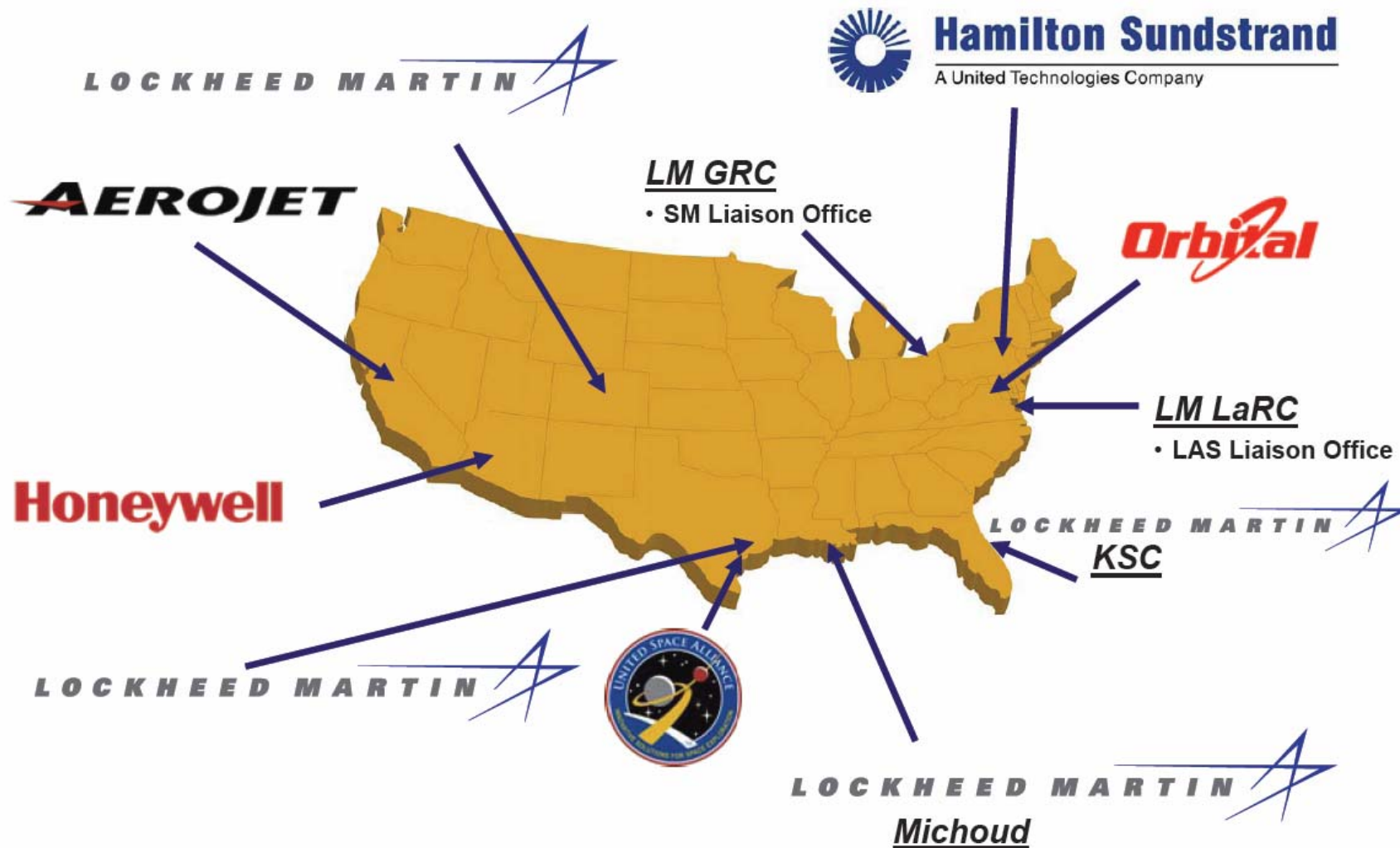
- NASA
 - PTCS System Manager
 - CM PTCS Lead
 - SM/SA PTCS Lead
 - LAS PTCS Lead
 - System Manager covers both analysis and hardware
- LM – Prime Contractor
 - Thermal Analysis Lead
 - LM Denver is primary contractor team
 - Subcontractors include:
 - Paragon: radiators
 - Orbital: LAS
 - Hamilton: ATCS
 - Aerojet: Thrusters, main engine
 - Honeywell: Avionics
 - PTCS Hardware Lead
 - LM Denver



Internal and external communications are essential and challenging

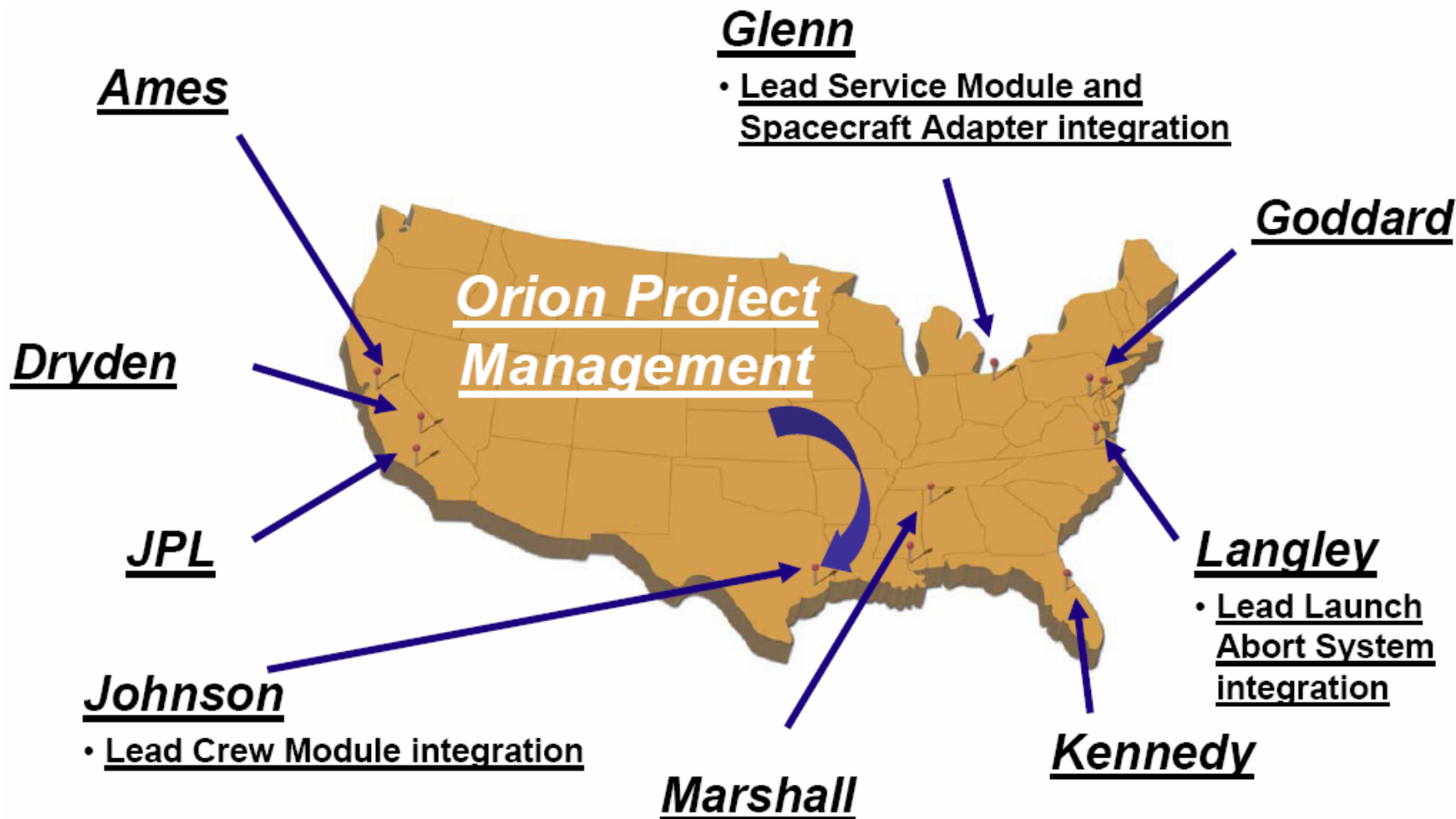


LM Contractor Team Locations



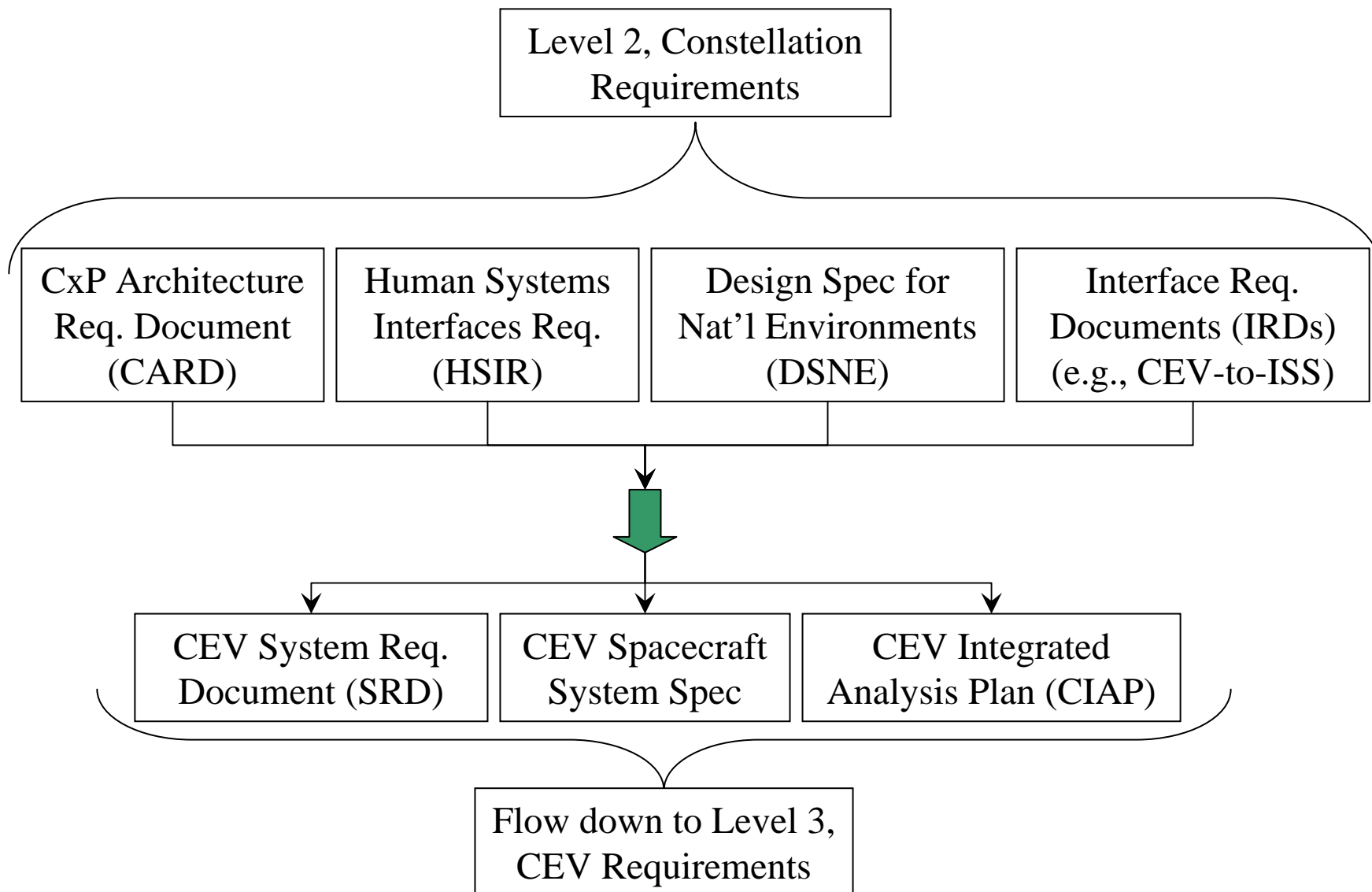


NASA Center Participation





Orion PTCS Overview Requirements





Requirements Examples



- From the CARD
 - The Constellation Architecture shall meet its requirements during and after exposure to the environments defined in CxP 70023, Constellation Architecture Design Specification for Natural Environments (DSNE).
- From the CEV SRD:
 - The CEV shall meet its functional and performance requirements during and after exposure to the environments defined in the CxP 70023, Constellation Program Design Specification for Natural Environments (DSNE), Sections 3.1, 3.2, 3.3, 3.5, 3.6 and 3.7.
- The HSIR (also mimicked in the CEV SRD) has several specific thermal items:
 - Touch Temperature limits
 - Condensation prevention on pressurized surfaces



Orion PTCS Overview DRMs



- Design Reference Missions
 - ISS missions
 - Crew Exchange (up to 6 crew members)
 - Cargo/Resupply (uncrewed)
 - 6 month duration
 - Low Lunar Orbit (LLO) Sortie missions
 - Low Earth Orbit (LEO) ... transit ... Short-term Lunar surface excursion ... transit ... re-entry
 - Up to 4 crew
 - LLO Outpost missions
 - LEO ... transit ... Extended Lunar surface excursion ... transit ... re-entry
 - Up to 4 crew



Orion Approaching the ISS

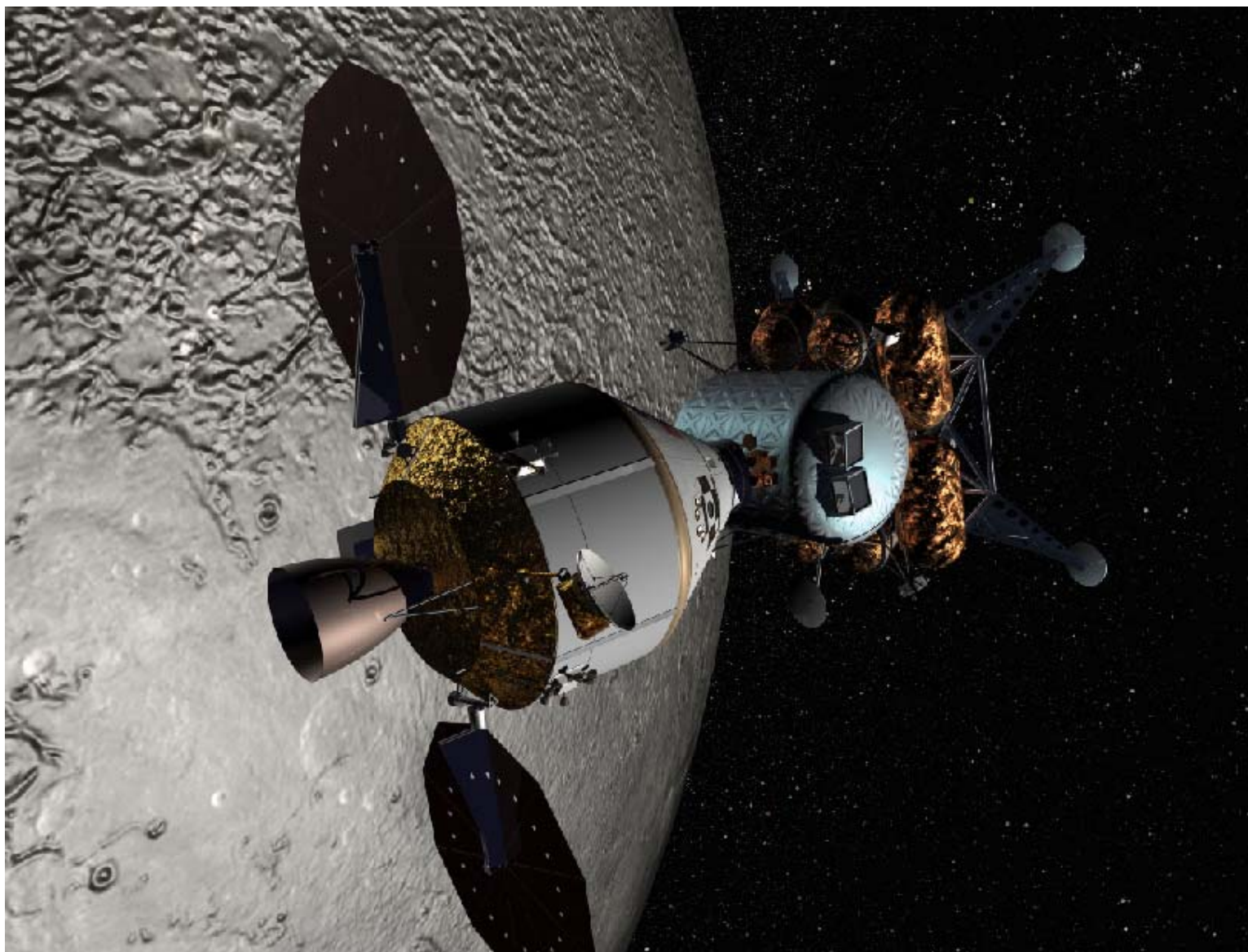


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Orion and Lunar Lander in LLO



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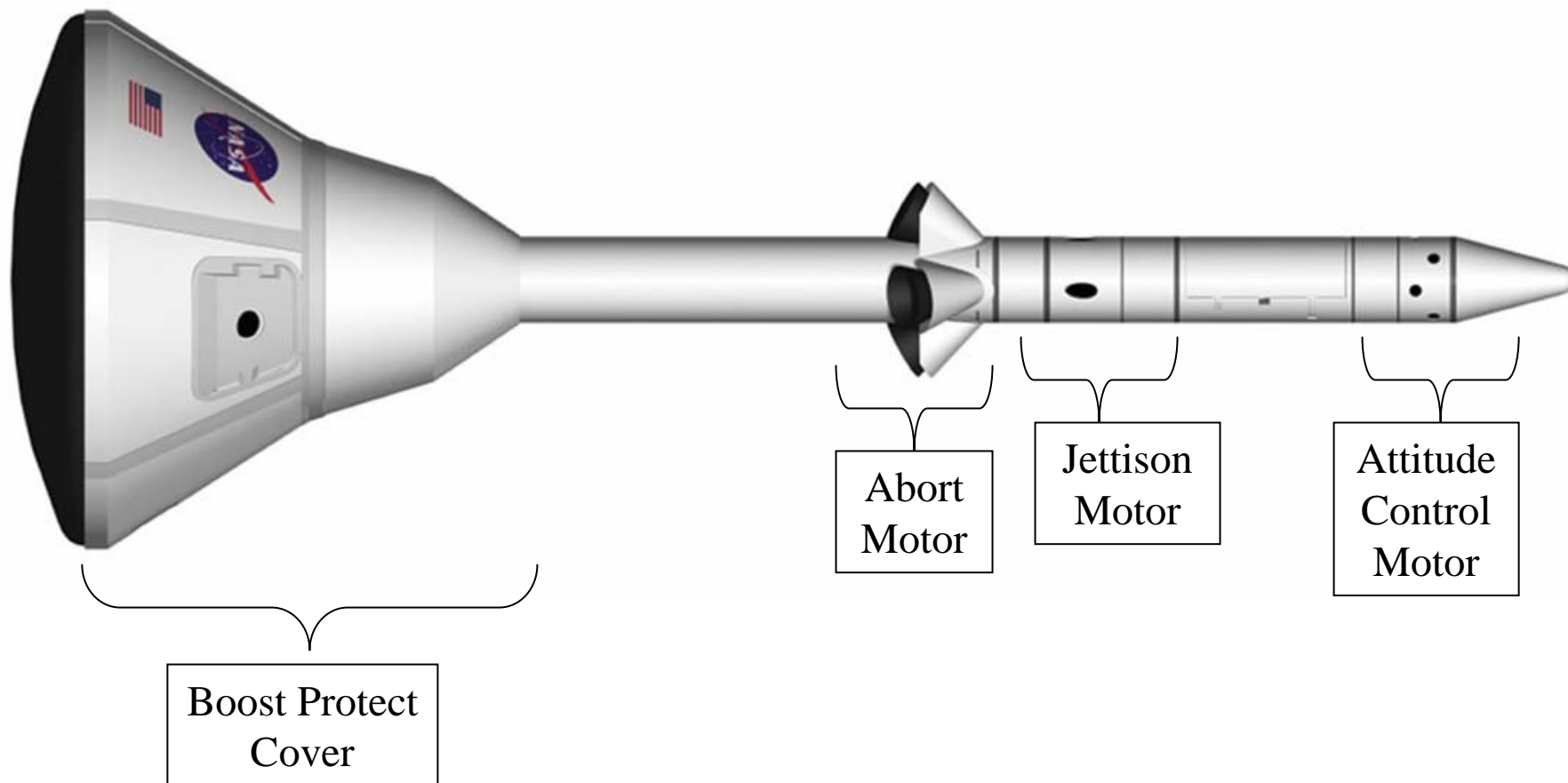
General LAS Description



- Launch Abort System
 - Main Purpose: Provide crew escape from catastrophic failure during early ascent phase.
 - Abort motors
 - Brief firings to extract crew from hazard
 - Jettison motors
 - Used to remove LAS from CM
 - Boost Protection Cover (BPC)
 - Protects CM surface from debris and ascent heating



LAS Image



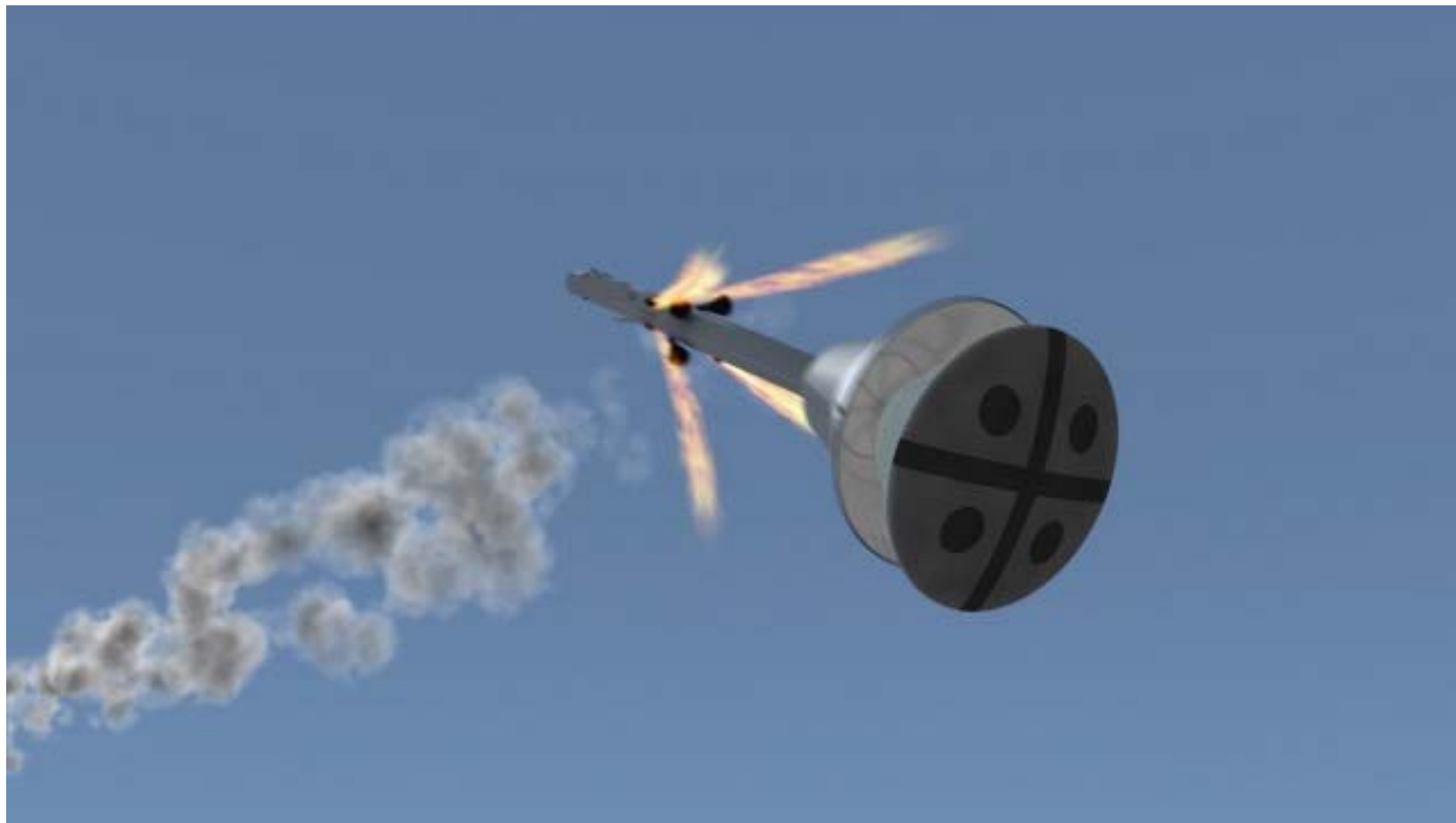


LAS Firing Images





LAS Separation



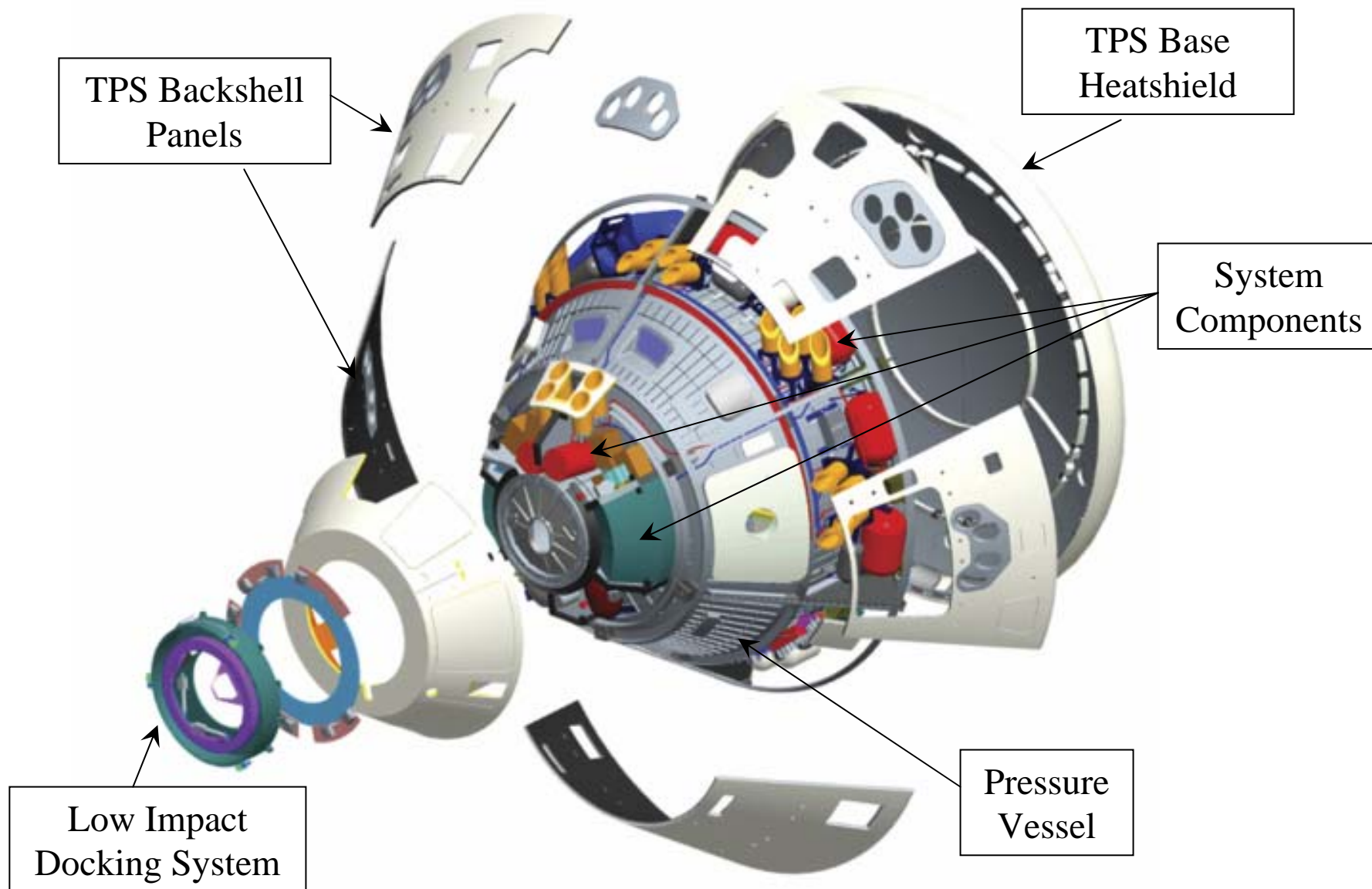


General CM Description

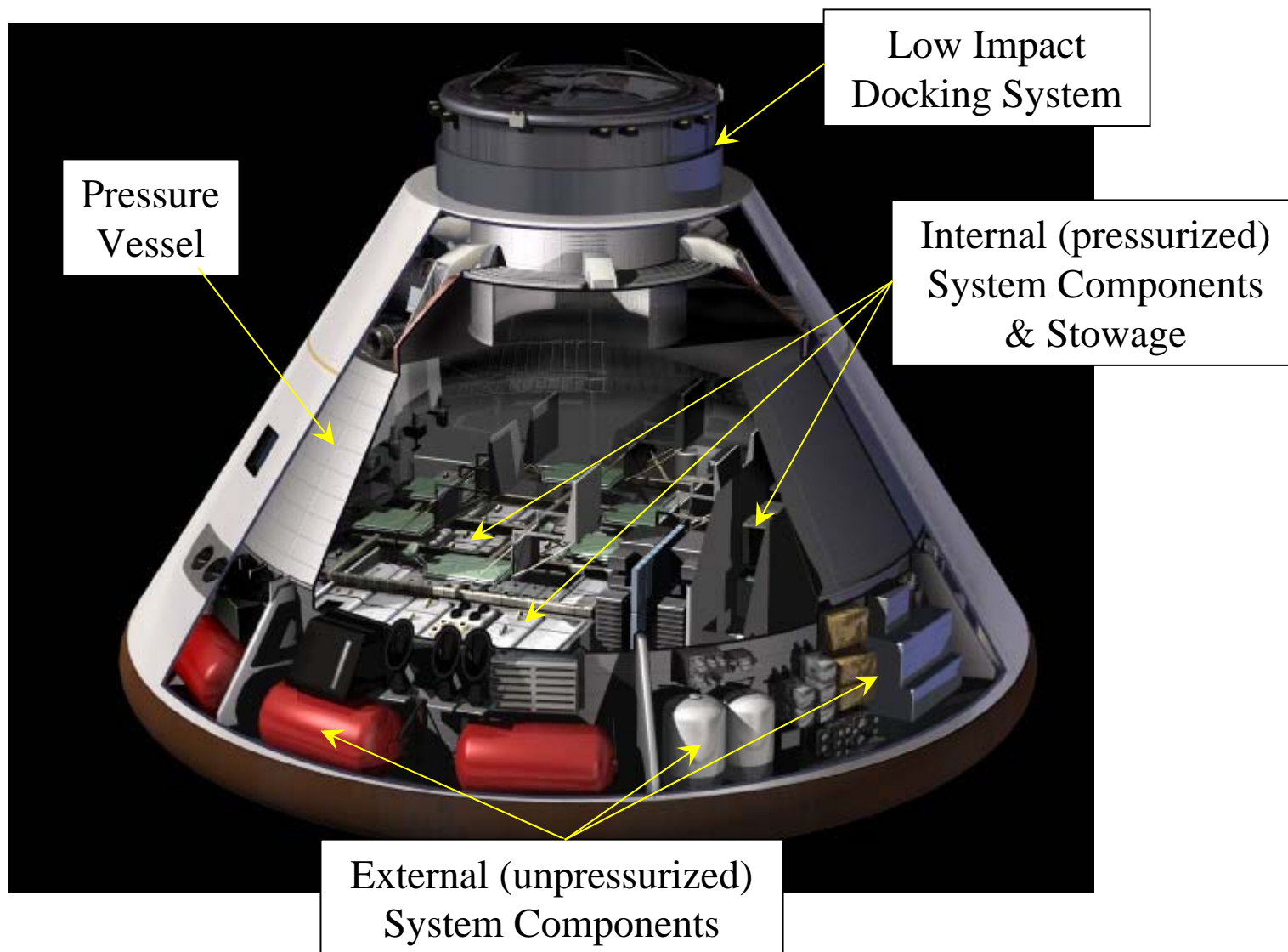


- Crew Module
 - Main Purpose: Provides living quarters for crew and re-entry capability
 - Thermal Protection System (TPS)
 - Backshell – conic section with penetrations
 - Heatshield – spherical base section and “shoulder region”
 - Pressure Vessel (PV)
 - Provide habitable volume and contains most avionics/electronics
 - Unpressurized area between TPS and PV houses some components
 - e.g. - Landing/Recovery (chutes, air bags), Power, Life Support (tanks), Propulsion (tanks/thrusters), Active Thermal Control (plumbing, coldplates)
 - Docking System
 - Low Impact Docking System (LIDS) being developed a Government Supplied Equipment.

Exploded View of CM



Cutaway View of CM





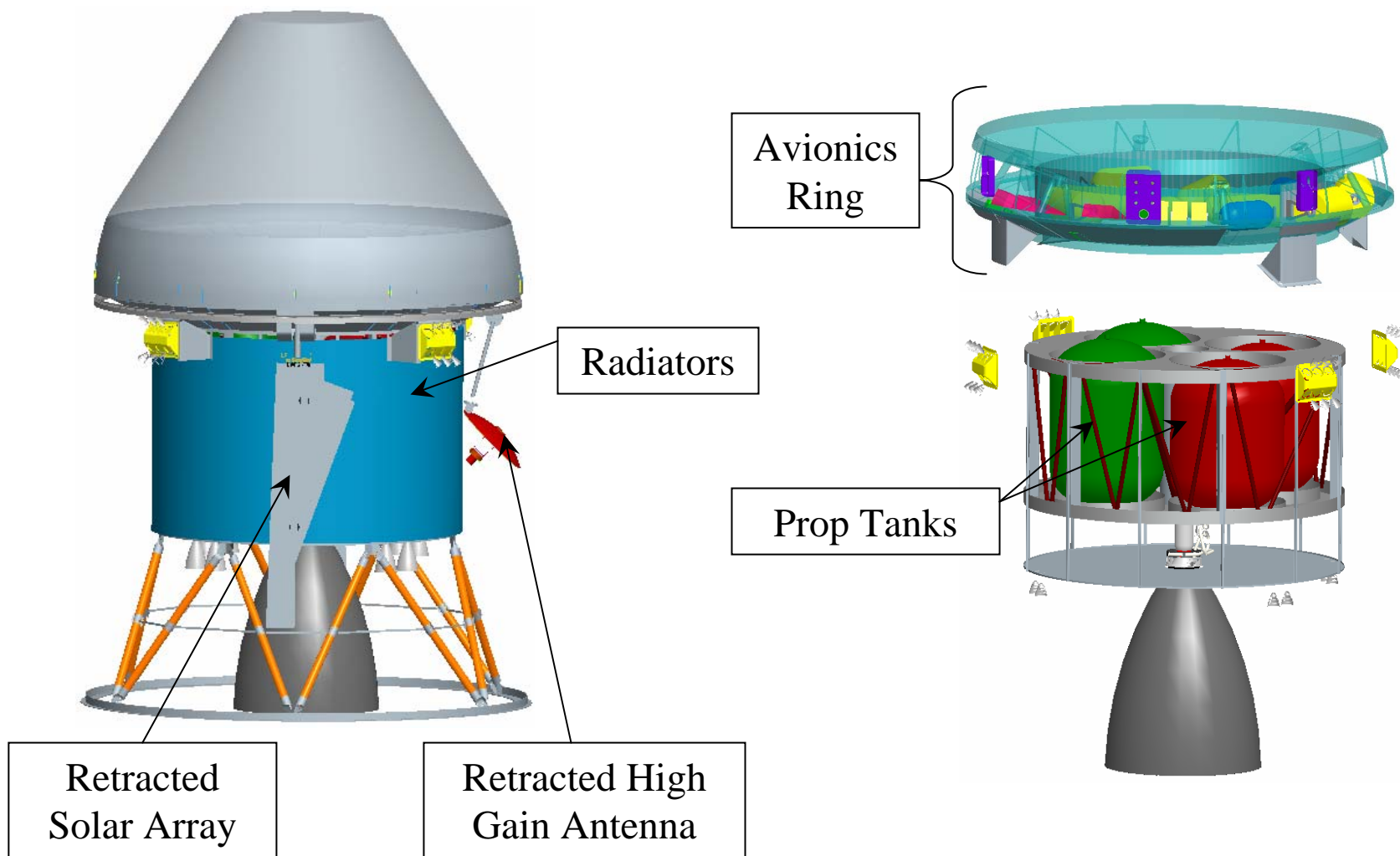
General SM Description



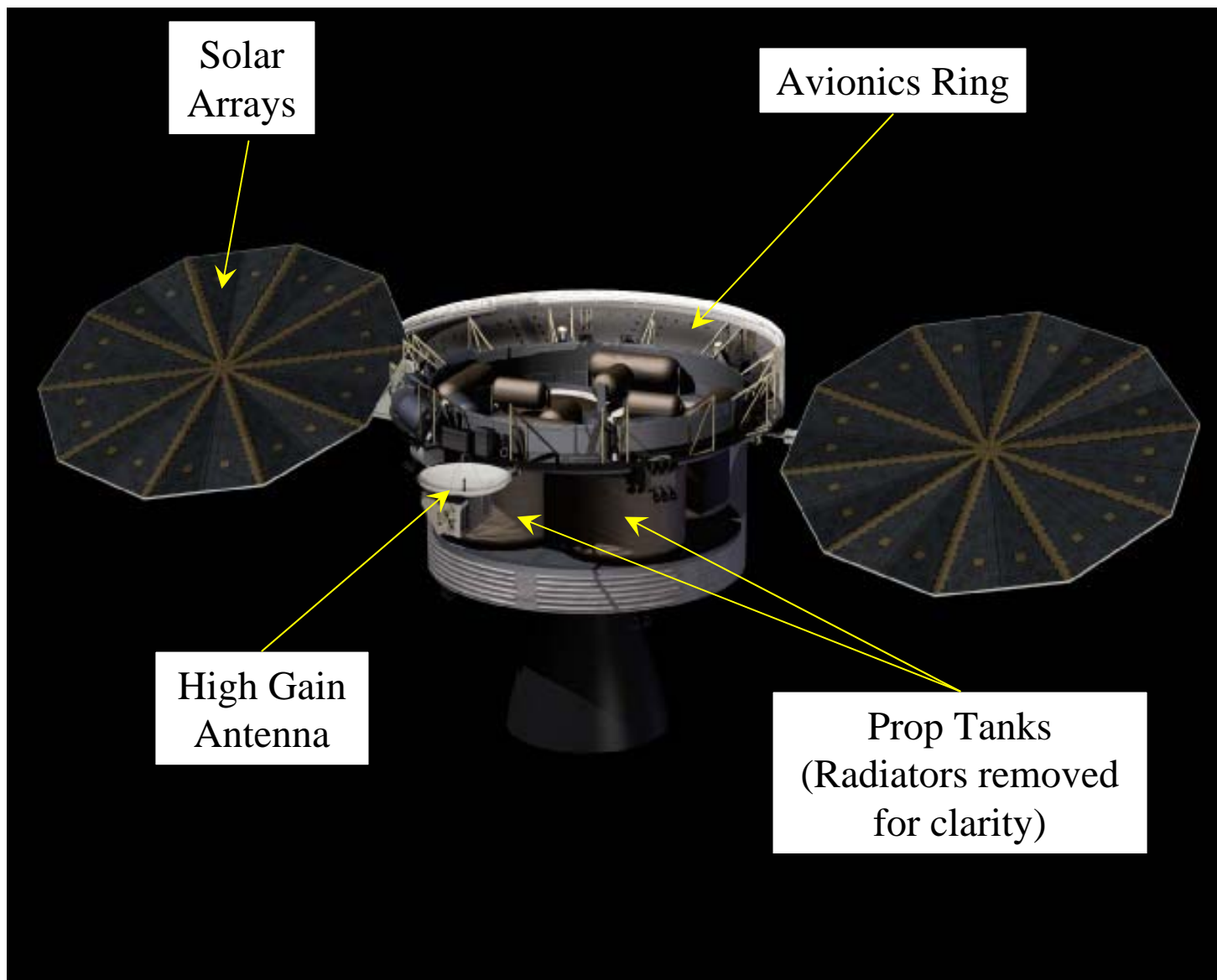
- Service Module
 - Main Purpose: Supplies propulsion, attitude control, power generation, heat rejections, and communications for the majority of the mission.
 - Note that the SM is discarded during re-entry, so each mission flies a brand new SM.
 - Radiators
 - Provide heat rejection of waste heat acquired from components in the CM and SM.
 - Prop tanks/thrusters & plumbing
 - The Prop system tanks, thrusters, and plumbing have an extensive heater system for temperature control.
 - Avionics ring
 - Mounts avionics/electronics for SM or overflow from the CM.



Service Module Images



SM Cutaway Image





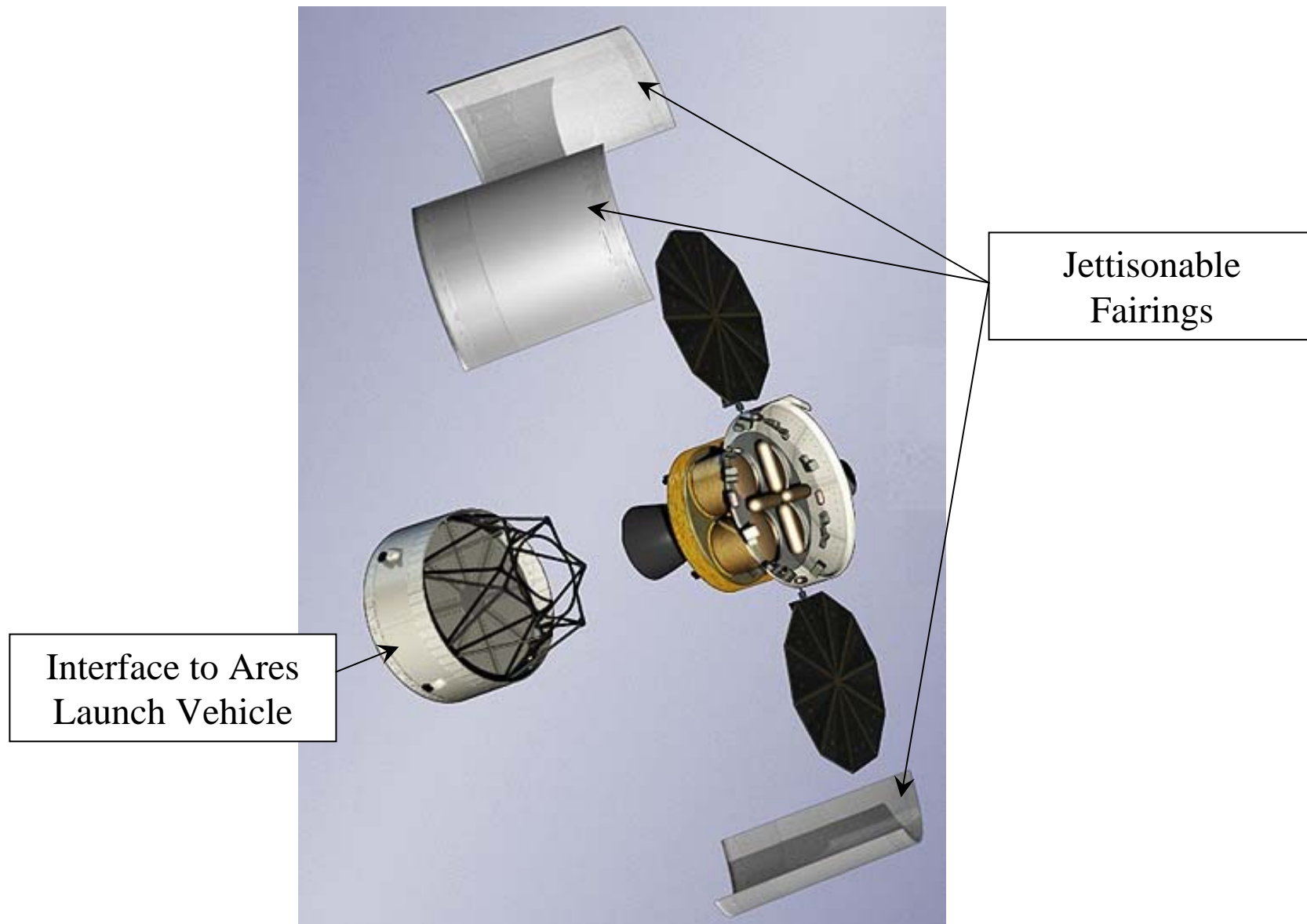
General Spacecraft Adapter Description



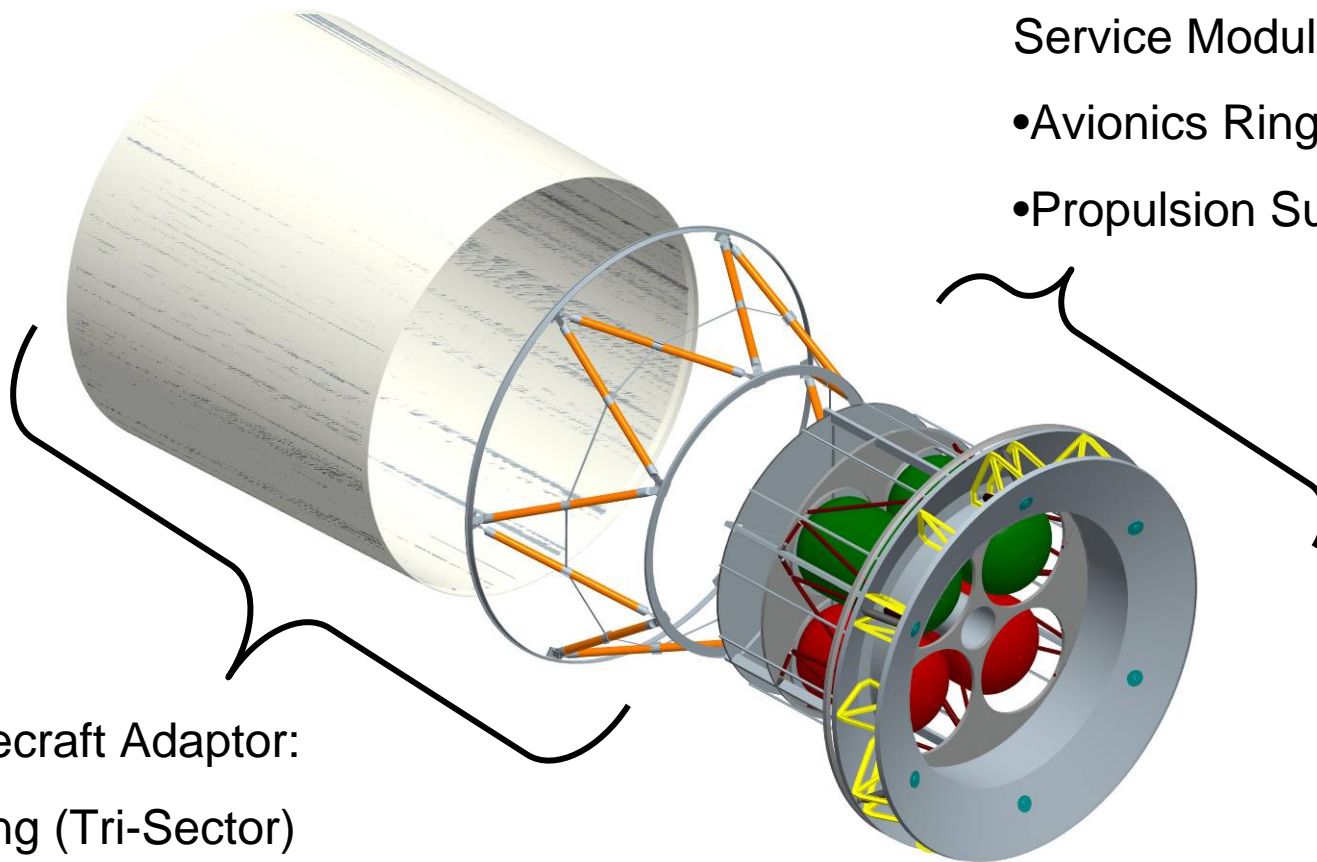
- Spacecraft Adapter (SA)
 - Main Purpose: Provides interface between Orion and Ares vehicles
 - Jettisonable Fairings
 - Protect radiators, solar arrays, and high gain antenna from ascent heating loads
 - The three panels are jettisoned seconds before LAS jettison.
 - Ares Launch Vehicle Interface
 - Structural interface connecting Orion to Ares
 - Also contains separation mechanism and umbilicals allowing Ares to communicate with Orion
 - The SA separates from Orion at Ares burnout



Spacecraft Adapter Image



Spacecraft Adapter Image



Service Module:

- Avionics Ring
- Propulsion Sub-Assembly

Spacecraft Adaptor:

- Fairing (Tri-Sector)
- W-Truss Assembly



Orion PTCS Overview – Natural Environments



- Two main documents define the CEV natural environments:
 - Design Specification for Natural Environments (DSNE, CxP 70023)
 - Natural Environments Definition for Design (NEDD, CxP 70044)
- The CEV on-orbit environments are currently split into 3 separate phases:
 - Transit
 - LEO
 - LLO



Transit Environments

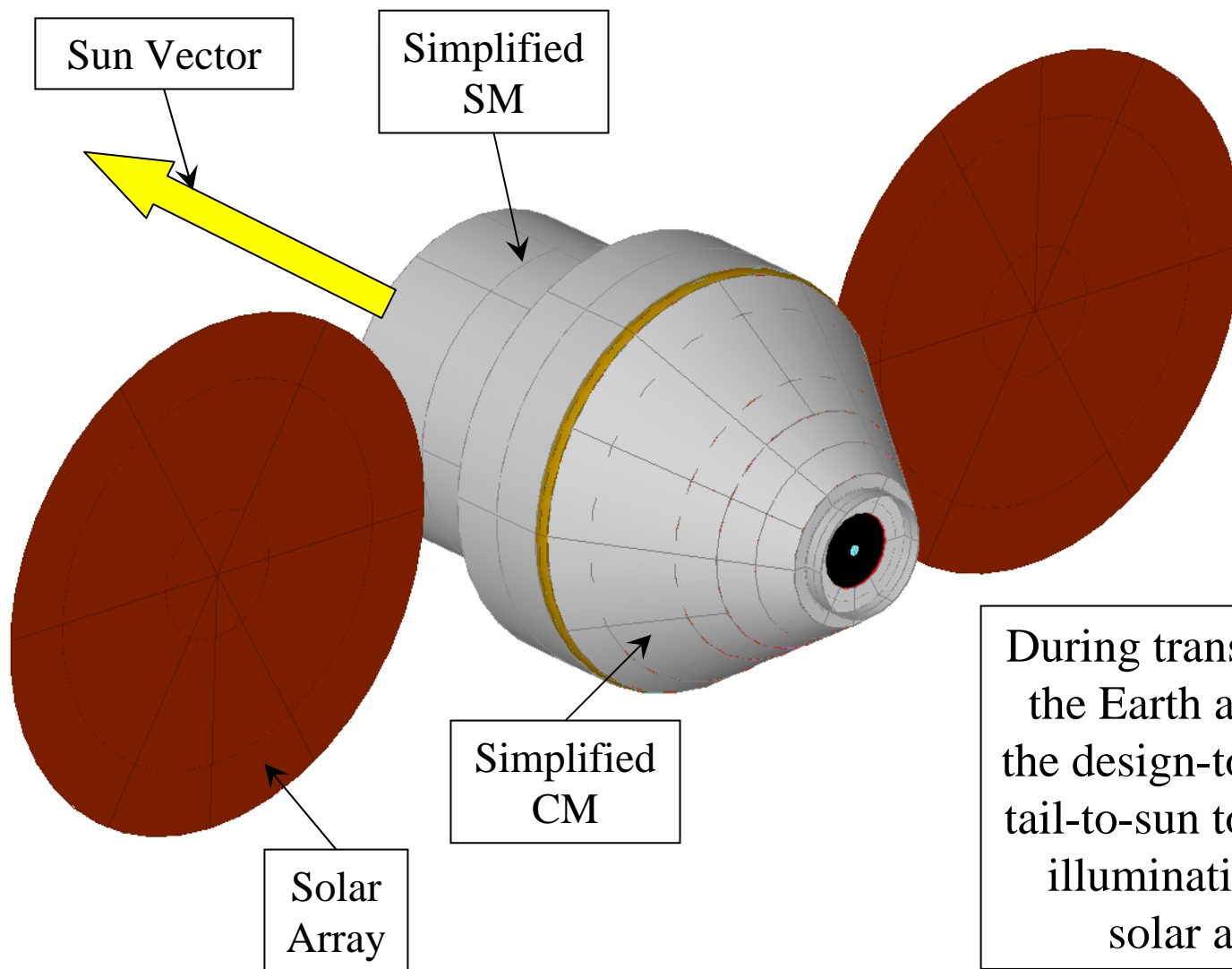


- Simplest of the three phases (from a natural environments perspective!) ... assumes planetary effects (albedo and Outbound Longwave Radiation (OLR)) are negligible.
- We have chosen to use the minimum and maximum solar constants defined in the NEDD
- Hot Environment

Solar Constant	451.2 BTU/Hr/ft ² (1422 W/m ²)
Albedo	0
OLR	0 BTU/Hr/ft ²

- Cold Environment

Solar Constant	417.2 BTU/Hr/ft ² (1315 W/m ²)
Albedo	0
OLR	0 BTU/Hr/ft ²



During transit between the Earth and Moon, the design-to attitude is tail-to-sun to allow full illumination of the solar arrays.



LEO Environments



- In Low Earth Orbit, the Solar Flux is readily defined in the DSNE. However, the albedo and OLR are defined in pairs.
 - The pairs account for the fact that the coldest (or hottest) albedo and coldest (or hottest) OLR do not occur simultaneously.
 - There are also averaging periods which neutralize short-term extremes.
 - Must cognizant of the vehicle/component's thermal time constant.
 - The pairs are also categorized by orbital inclination.
- A solar zenith angle (SZA) correction factor must also be applied to the albedo.
 - The NEDD defines the SZA correction as a 4th order polynomial
 - The equation can be directly incorporated into Thermal Desktop.



LEO Environments, Continued



- The Orion CEV PTCS analysis uses the following assumptions:
 - An Averaging Time sufficient for the model's thermal time constant is used when estimating the albedo and OLR
 - The Combined Minimum (or Maximum) albedo/OLR pair is appropriate given the thermal model's optical property sensitivities.
 - Note that if the analyst feels their model is more sensitive to either the solar or infrared spectrum, then he/she should refer to the DSNE/NEDD for different values.
 - The analyst assigns a value of True Anomaly = 0° to occur at orbital noon.
 - The solar zenith angle is defined by the following relationship
$$SZA = \cos^{-1}(\cos(\beta) * \cos(\nu))$$
 - Where β is the beta angle and ν is the true anomaly.



LEO Environments, Continued



- LEO Natural Environments for an ISS Hot Case

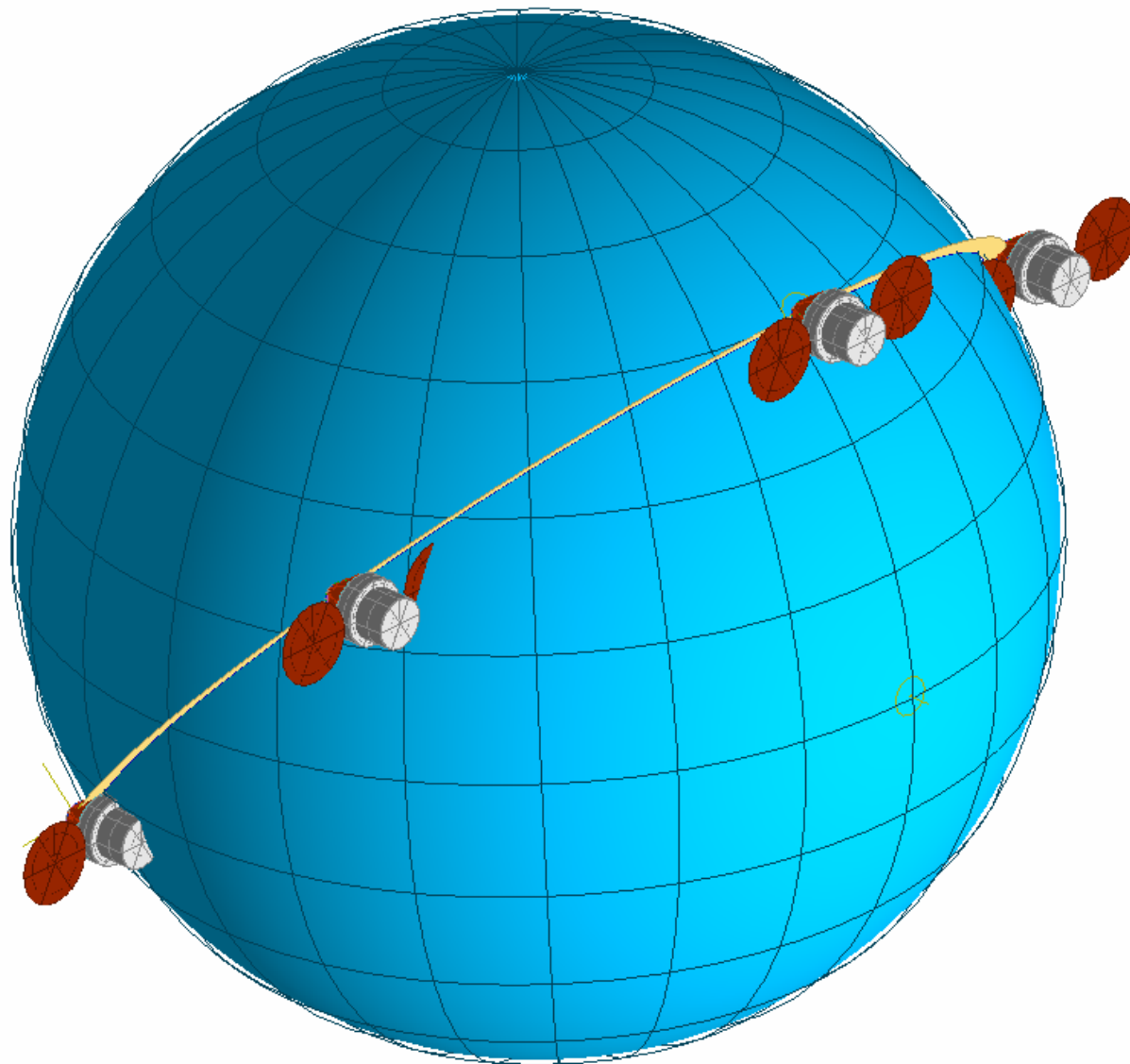
Solar Constant	448.6 BTU/Hr/ft ² (1414 W/m ²)
Albedo	0.28 + SZA Correction
OLR	81.9 BTU/Hr/ft ² (258 W/m ²)

- LEO Natural Environments for an ISS Cold Case

Solar Constant	419.5 BTU/Hr/ft ² (1322 W/m ²)
Albedo	0.17 + SZA Correction
OLR	68.9 BTU/Hr/ft ² (217 W/m ²)



CEV in Tail-to-Sun LEO, $\beta = -45^\circ$





LLO Environments



- In Low Lunar Orbit, the solar constant and albedo are relatively straightforward, but the OLR is complicated.
 - The NEDD provides a formula for calculating the day-side lunar OLR. The formula requires:

- The average albedo, \bar{a} , 0.15
- The Solar Constant, S_o , at 1 AU, 1367 W/m²
- The solar zenith angle, $\cos(i)$
- The Sun-Moon distance, R_L , in AU

$$OLR_{Day-Side} \approx \frac{(1 - \bar{a}) S_o \cos(i)}{R_L^2}$$

- On the night-side of the moon, the OLR is calculated from:

$$OLR_{Night-Side} \approx \varepsilon \sigma T_s^4$$

- ε is the lunar emissivity
- σ is the Stefan-Boltzmann constant.
- T_s is the lunar surface temperature



LLO Environments, Continued



- LLO Natural Environments for a Hot Case

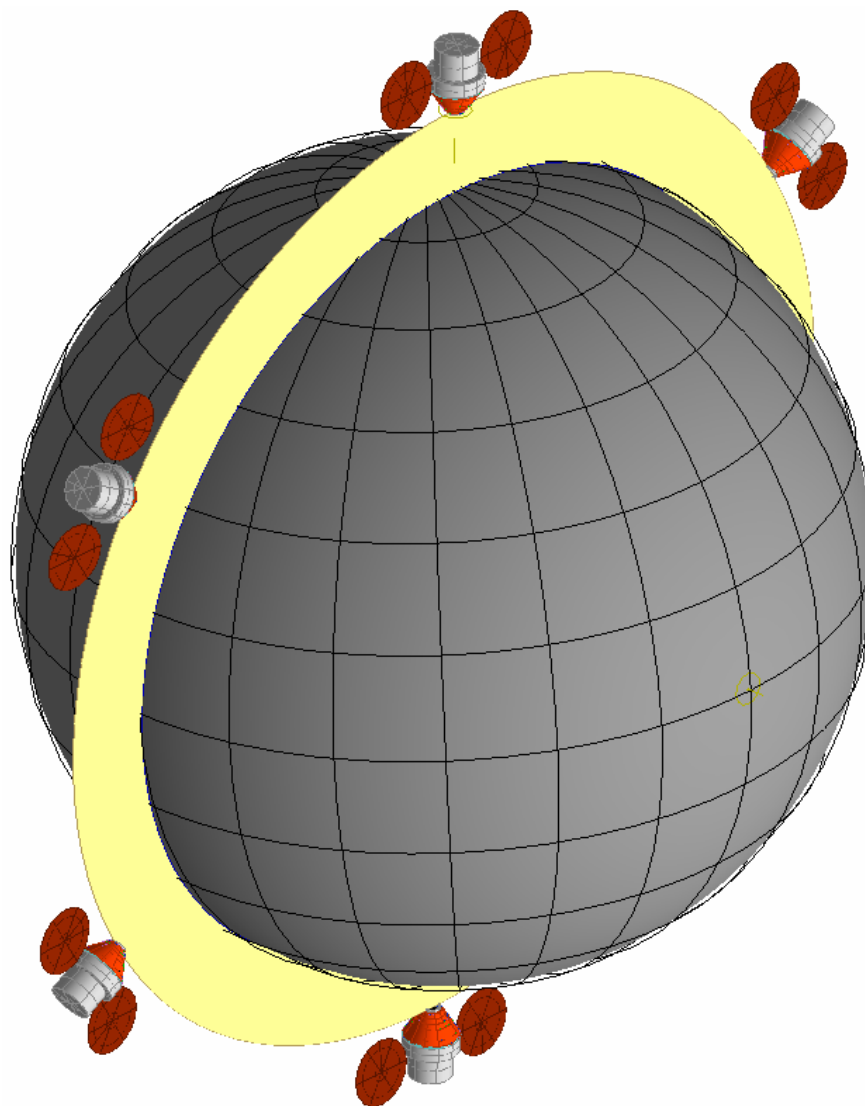
Solar Constant	451.2 BTU/Hr/ft ² (1422 W/m ²)
Albedo	0.2
OLR Day-Side	383cos(<i>i</i>) BTU/Hr/ft ² (1208cos(<i>i</i>) W/m ²)
OLR Night Side	11.8

- LLO Natural Environments for Cold Case

Solar Constant	417.2 BTU/Hr/ft ² (1315 W/m ²)
Albedo	0.07
OLR Day-Side	355cos(<i>i</i>) BTU/Hr/ft ² (1118cos(<i>i</i>) W/m ²)
OLR Night Side	3.7



CEV in Nose Nadir LLO, $\beta = -85^\circ$





Other CEV Environments



- Pre-launch
- Ascent Aeroheating liftoff to orbit injection (continuum and non-continuum heating)
 - Nominal ascent
 - Abort back to earth
 - Abort to orbit
 - Aeroheating
- Mated to ISS
- Re-entry Heating
 - Lunar return is based on a skip re-entry
- Post-landing



Images of CEV Mated to ISS at Node 2



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Orion PTCS Overview

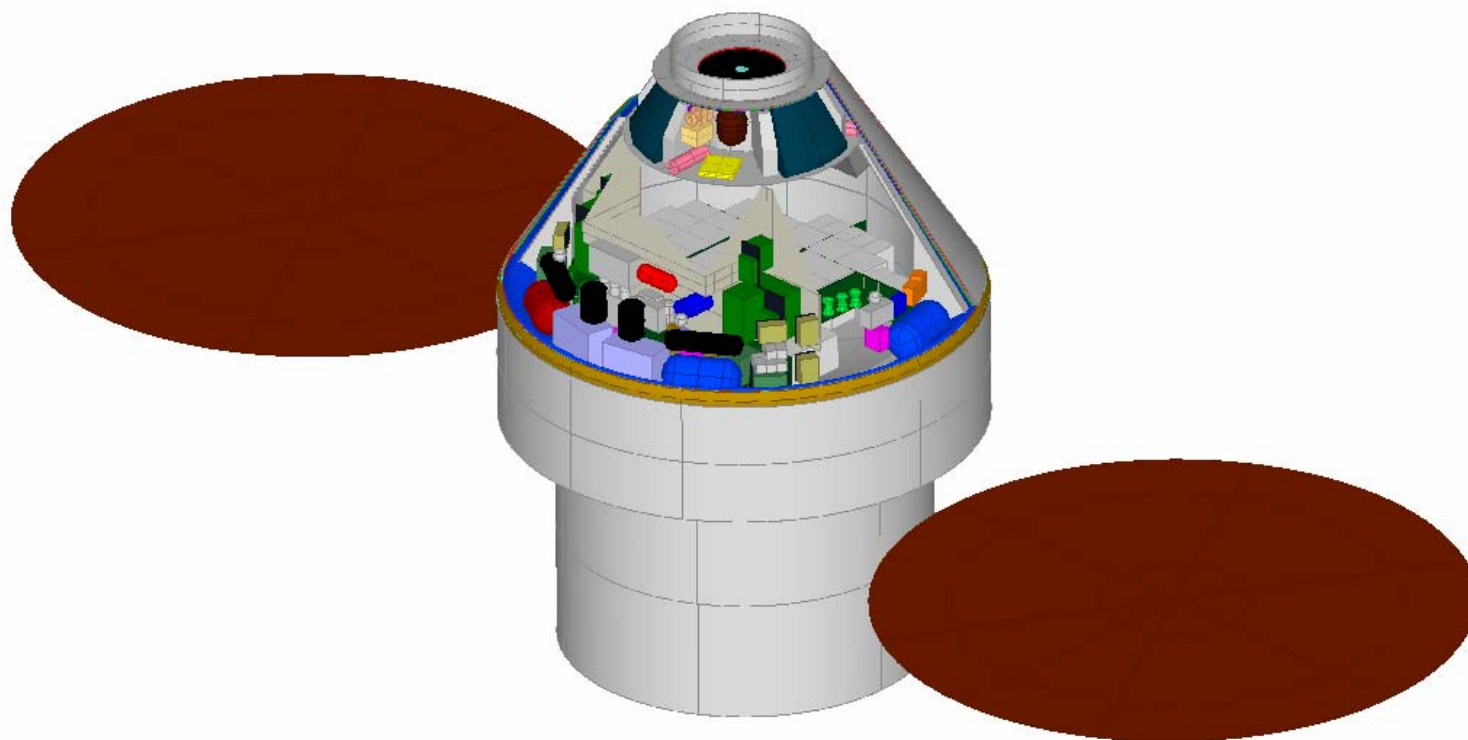
Thermal Models



- Thermal Models
 - Both NASA and LM are using Thermal Desktop 5.0 and AutoCAD 2007
 - Most subcontractors are also using these programs
 - Results in an efficient model exchange, no model conversion
 - Generated an unofficial Orion “user group” where modeling techniques, approaches, and help are shared
 - NASA and LM are developing “independent” models during the initial phase of the program.
 - “Independent” in that NASA is making its own models, but the same folks reviewing the LM models are also building the NASA models.
 - There is bound to be some cross-over
 - Different models are used to corroborate results during the early phases of the design.
 - Will eventually have one official Orion PTCS model
 - Will try to integrate closely with ATCS model so there will be one single Orion Thermal model.



Simplified Integrated Orion Thermal Model





Thermal Model Evolution



- Current thermal models are simple
 - Most components are represented as a single node with the appropriate mass, internal power dissipation (where applicable), and best-guess material/optical properties.
 - Exterior surfaces are smooth and do not contain penetrations, windows, etc.
- As the design matures, component models will be refined
 - Subcontractors will deliver component thermal models
 - A detailed model to completely describe the component
 - And a smaller, simplified model to integrate into the system level model.
 - These will be correlated to test data



Thermal Model Evolution, Cont.



- At the integrated system level:
 - Correlated, simplified component models will be incorporated.
 - TPS Backshell penetrations and similar details will be incorporated
 - i.e., solar arrays, SM main engine, plumbing routing, component attachments, etc.
 - Development testing of specific thermal connections may be performed to bound particular parameters.
 - The integrated model will then be correlated to system Thermal Balance and Qual test (thermal vacuum) data.
- The goal is to have a fully certified PTCS model for use for testing and on-orbit predictions.
 - If the system-level model predicts violations then the more detailed component models can be used.
 - Will use the certified model for acceptance test predictions, orbital flight test predictions, and mission timelines.



Passive Thermal Challenges



- LAS Thermal Areas of Interest/Challenges
 - Propellant temperatures
 - The extreme cold case at KSC make it difficult to keep the abort propellant within temperature limits during the transportation to the launch pad and pre-launch operations.
 - BPC/Crew Module interface
 - The thermal interface between the BPC and TPS is complex. Testing will be required to provide a good estimation of this parameter.
 - Additionally, there are concerns about the BPC damaging the TPS coating during separation.



Passive Thermal Challenges, Cont.



- CM Thermal Areas of Interest/Challenges
 - Ascent Heating
 - After BPC jettison, the LIDS and TPS backshell are exposed to aeroheating.
 - TPS/Pressure Vessel Heat Leak
 - This involves the optical properties of the TPS, the structural attachment of the TPS to the pressure vessel, and the heater power needed to preclude condensation inside the PV habitable volume.
 - Defining Heat Leak/Gain with Cabin Air
 - With the current ECLSS/ATCS design, that team requires information on the heat leak/gain from components and the PV into the air. Requires estimating heat transfer coefficients or thermal conductivity for different regions/zones of air in the vehicle.
 - Re-Entry heating and soakback
 - During re-entry, the TPS bondline reaches elevated temperature. PTCS analysis will determine how this heat soaks into the vehicle and effects component temperatures, cabin air, crew comfort, etc.



- SM Thermal Areas of Interest/Challenges
 - SM Prop Temperatures
 - The Prop team has identified a narrow temperature range for prop components. Requires a tight heater control band and thermal isolation from other SM components.
 - SM Radiator design and environments
 - The post-fairing jettison ascent aeroheating on the radiators limit heat rejection in the early flight phases.
 - LLO high OLR environment make radiator sizing difficult



Orion PTCS Overview Testing



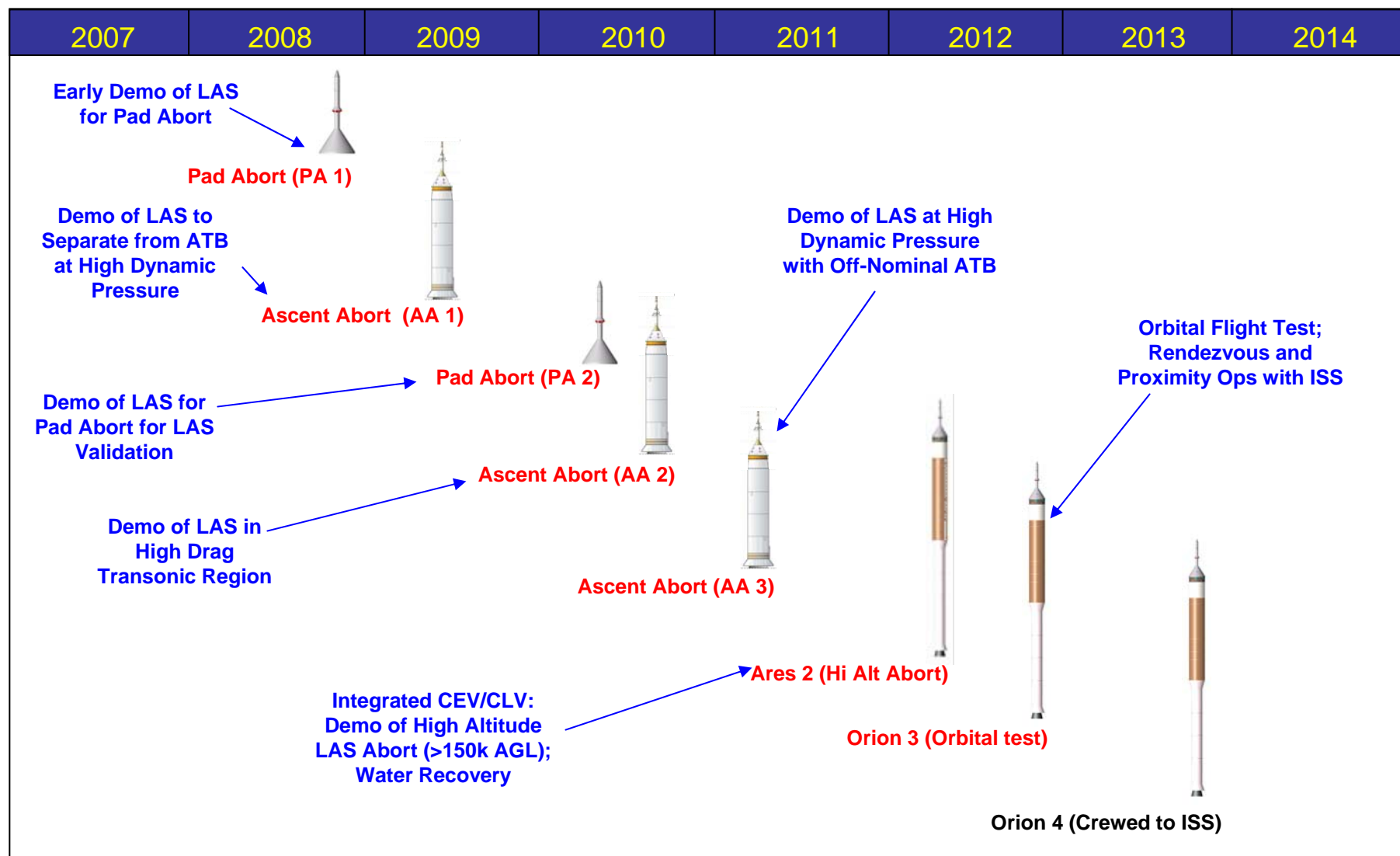
- Flight Testing – several early flight tests are planned
 - Pad Abort 1 and Ascent Abort 1 are the near-term tests.
 - Will demonstrate on-pad and max Q abort capability
- For thermal, the controlling test document is the Constellation Environmental Qualification and Acceptance Test Requirements (CEQATR)
 - It defines how thermal balance, thermal cycle, and thermal vac testing will be conducted.
 - It mainly adheres to MIL-STD-1540, but the cold test limit may be lowered after a review of other industry practices.
 - This document is applicable to both the unit (box) and system (up to and including the full Orion vehicle) level for Qual and Acceptance tests.
 - Thermal test plans include provision for development testing, qual testing, and acceptance testing.



CEV Flight Test Concept



Crew Exploration Vehicle Project Office





Qual/Acceptance Temperatures per 1540

